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E-7009

NASA Technical Memorandum 105689

# Validation Test of Advanced Technology for IPV Nickel–Hydrogen Flight Cells — Update

John J. Smithrick  
*Lewis Research Center*  
*Cleveland, Ohio*

and

Stephen W. Hall  
*Naval Weapon Support Center*  
*Crane, Indiana*

Prepared for the  
27th Intersociety Energy Conversion Engineering  
sponsored by SAE, ACS, AIAA, ASME, IEEE, AIChE, and ANS Conference  
San Diego, California, August 3–7, 1992



E-7069

TM-105689

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VALIDATION TEST OF ADVANCED TECHNOLOGY FOR IPV NICKEL-HYDROGEN  
FLIGHT CELLS—UPDATE

John J. Smithrick  
National Aeronautics and Space Administration  
Lewis Research Center  
Cleveland, Ohio 44135

and

Stephen W. Hall  
Naval Weapon Support Center  
Crane, Indiana 47522

Replace page 6 with revised page 6.

TABLE I. - CAPACITY OF HUGHES FLIGHT CELLS CONTAINING 26 AND 31 PERCENT KOH ELECTROLYTE

Cell	Capacity, <sup>a</sup> A-hr	KOH concentration, percent
1	59.0	31
2	59.9	31
3	59.0	31
4	53.8	26
5	53.2	26
6	52.3	26

<sup>a</sup> Discharge at 1.4 C rate, 10 °C.

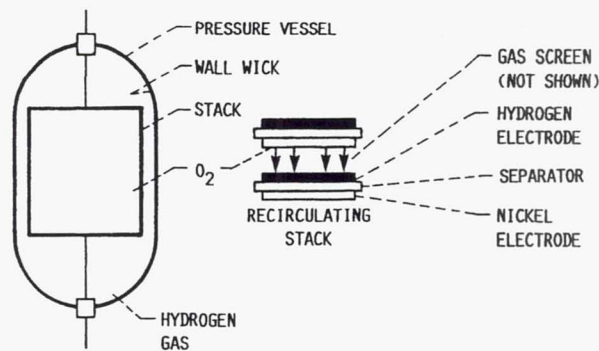


FIGURE 1.—ILLUSTRATION OF HUGHES RECIRCULATING STACK INDIVIDUAL PRESSURE VESSEL NICKEL-HYDROGEN CELL.

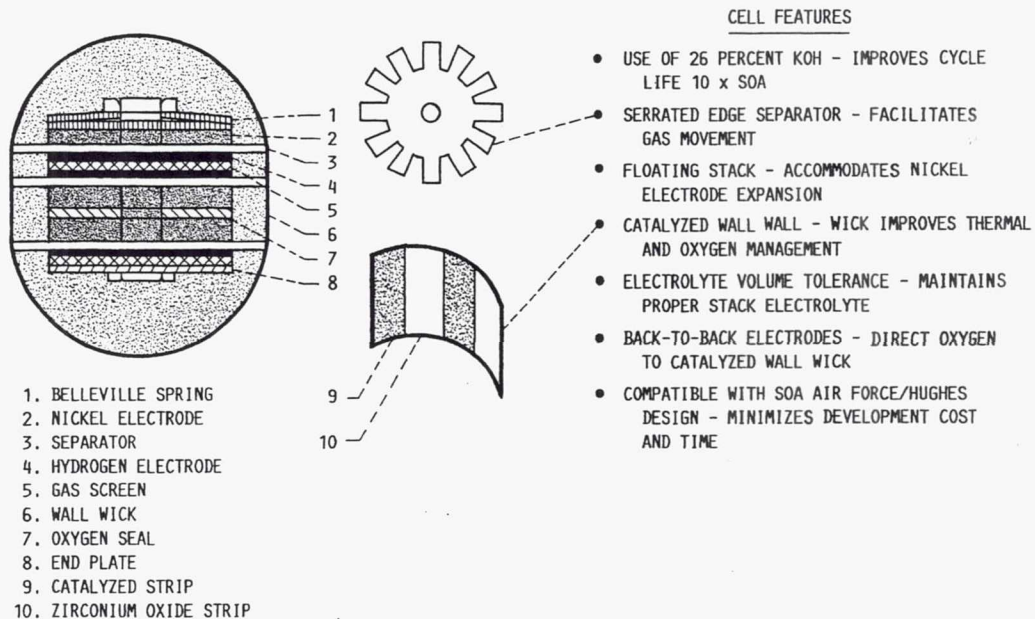


FIGURE 2.—NASA ADVANCED DESIGN IPV NICKEL-HYDROGEN CELL-CATALYZED WALL WICK.



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### ABSTRACT

Individual pressure vessel (IPV) nickel-hydrogen technology was advanced at NASA Lewis and under Lewis contracts with the intention of improving cycle life and performance. One advancement was to use 26 percent potassium hydroxide (KOH) electrolyte to improve cycle life. Another advancement was to modify the state-of-the-art cell design to eliminate identified failure modes. The modified design is referred to as the advanced design.

A breakthrough in the Low-Earth-Orbit (LEO) cycle life of IPV nickel-hydrogen cells has been previously reported. The cycle life of boiler plate cells containing 26 percent KOH electrolyte was about 40 000 LEO cycles compared to 3500 cycles for cells containing 31 percent KOH. The boiler plate test results are in the process of being validated using flight hardware and real time LEO test at the Naval Weapons Support Center (NWSC), Crane, Indiana under a NASA Lewis Contract.

An advanced 125 Ah IPV nickel-hydrogen cell was designed. The primary function of the advanced cell, is to store and deliver energy for long-term, LEO spacecraft missions. The new features of this design are: (1) use of 26 rather than 31 percent KOH electrolyte, (2) use of a patented catalyzed wall wick, (3) use of serrated-edge separators to facilitate gaseous oxygen and hydrogen flow within the cell, while still maintaining physical contact with the wall wick for electrolyte management, and (4) use of a floating rather than a fixed stack (state-of-the-art) to accommodate nickel-electrode expansion due to charge/discharge cycling. The significant improvements resulting from these innovations are extended cycle life; enhanced thermal, electrolyte, and oxygen management; and accommodation of nickel-electrode expansion. The advanced cell design is in the process of being validated using real time LEO cycle life testing of NWSC, Crane, Indiana. An update of validation test results confirming this technology is presented.

### INTRODUCTION

The state of development of individual pressure vessel nickel-hydrogen battery cells is such that they are acceptable for geosynchronous orbit (GEO) applications since not many cycles are required over the life of the battery system (1000 cycles, 10 years). There are 20 communication satellites in GEO using IPV nickel-hydrogen batteries (Ref. 1). For the demanding Low-Earth-Orbit (LEO) applications, however, the current cycle life at moderate-to-deep depths-of-discharge (40 to 80 percent) should be improved. Battery cycle life has a major impact on life cycle cost for LEO applications such as Space Station Freedom (30 year life). The primary drivers are transportation to orbit and battery cost.

IPV nickel-hydrogen technology was advanced at NASA Lewis and under Lewis Contracts with the intention of improving cycle life and performance. One advancement was to use 26 percent KOH electrolyte to improve cycle life. Another advancement was to modify the state-of-the-art cell design to eliminate identified failure modes. The modified design is referred to as the advanced design.

The influence of potassium hydroxide electrolyte concentration on cycle life was investigated at Hughes Aircraft Company under a NASA Lewis Contract. Hughes reported a breakthrough in LEO cycle life (Refs. 2 and 3). Boiler plate cells containing 26 percent KOH were cycled for about 40 000 accelerated cycles at 80 percent depth-of-discharge (DOD) and at 23 °C, compared to 3500 cycles for cells containing 31 percent KOH. These results are in the process of being validated using flight hardware and real time LEO test under a NASA Lewis Contract with the Naval Weapons Support Center, Crane, Indiana.

The advanced design for an IPV nickel-hydrogen cell was conceived with the intention of improving cycle life at modest-to-deep depths-of-discharge (40 to 80 percent). The approach was to review IPV nickel-hydrogen cell



designs and results of cycle life tests conducted in-house and by others to identify areas where improvements could result in a longer life (Refs. 4 to 10). The feasibility of the design was demonstrated using 6 Ah boiler plate cells (Ref. 11). The advanced design is in the process of being validated using 125 Ah flight cells and real time test under a NASA Lewis Contract with the NWSC, Crane, Indiana.

In this report results of the validation tests which were presented at the 1991 IECEC will be updated (Refs. 12 and 13).

## MEASUREMENTS AND PROCEDURES

For both the 48 and 125 Ah cells, the quantities measured every 2.4 min for each cell during charge and discharge and their accuracies are: current ( $\pm 2.0$  percent), voltage ( $\pm 0.001$  percent), pressure ( $\pm 1$  percent), and temperature ( $\pm 1$  percent). Charge and discharge ampere-hour capacities are calculated from current and time. Charge-to-discharge ratio (ampere-hours into cell on charge to ampere-hours out on discharge) is calculated from the capacities. Cell charge and discharge currents are calculated from the voltage measured across a shunt, using an integrating digital voltmeter. Cell pressure is measured using a strain gauge located on the cell dome. The temperature was measured using a thermistor located on the center of the pressure vessel dome. The thermistor is mounted using a heat sink compound to insure good thermal contact.

For the 48 Ah cells, prior to cell final hydrogen gas adjustment, the nickel electrodes were positively charged, which results in a 0 psia hydrogen gas pressure. After completion of acceptance testing the cells were discharged at the C/10 rate (4.8 A) to 0.1 V or less. The cells were shipped to NWSC, Crane, Indiana, where they were stored at 10 °C under trickle charge at C/200 for 31 days. After storage the discharge ampere-hour capacity acceptance test was repeated. The capacity was measured after charging the cells at the C/2 rate (24 A) for 2.0 hr, then C/10 for 6 hr followed by a 0.5 hr open circuit stand. The discharge capacity was measured to 1.0 V at each of the following rates: C/2, C, 1.4, and 2 C.

Prior to undergoing cycle life testing the capacity retention after a 72 hr open circuit stand (10 °C) was measured for each cell. For the cycle life test the cells were connected electrically in series to form a six cell pack. The cycle regime was a 90 min LEO orbit consisting of a 54 min charge at a constant 0.93 C rate (44.7 A) followed by a 36 min discharge at a 1.33 C rate (64 A). The charge to discharge ratio was 1.048. The depth-of-discharge was 80 percent of name plate capacity (48 Ah). During the cycle life test the cooling plate temperature was maintained at  $10 \pm 2$  °C. Cell failure for this test was defined to occur when the discharge voltage degrades to 1.0 V during the course of the 36 min discharge.

For the 125 Ah cells, after completion of activation by the manufacturer, the precharge hydrogen pressure was set to 0 psig (14.5 psia) with the nickel electrodes in

the fully discharged state. After completion of the acceptance testing the cells were discharged at the C/10 rate (12.5 A) to 0.1 V or less and the terminals were shorted. The cells were shipped to NWSC, Crane, where they were stored at open circuit, and discharged, at 0 °C for 52 days. After storage the discharge ampere-hour capacity acceptance test was repeated. The capacity was measured after charging the cells at the C/2 rate (62.5 A) for 2 hr then C/10 for 6 hr followed by a 0.5 hr open circuit stand. The discharged capacity was measured to 1.0 V for each of the following rates: C/2, C, 1.4 C, and 2 C.

Prior to undergoing cycle life testing the capacity retention after a 72 hr open circuit stand (10 °C) was measured for each cell. For the cycle life test the cells were connected electrically in series to form a six cell pack. The cycle regime is a 90 min LEO orbit consisting of a 54 min charge at a constant 0.69 C rate (87 A) followed by a 36 min discharge at a C rate (125 A). The charge-to-discharge ratio was 1.04. The depth-of-discharge was 60 percent of name plate capacity (125 Ah). During the cycle life test the cooling plate temperature was maintained at  $10 \pm 2$  °C. Cell failure for this test was defined to occur when the discharge voltage degrades to 1.0 V during the course of the 36 min discharge.

## EXPERIMENTAL

**TEST FACILITY** – The facility is capable of testing 45 battery packs with maximum of 10 cells electrically connected in series per pack. Each pack has its own charge and discharge power supply controlled by a computer which is programmed to satisfy the particular test requirements. During testing, each pack is scanned every 2.4 min to compare data such as voltage, temperature, and pressure with programmed limits. If a parameter is out of limit an alarm will be initiated and a message will be typed out identifying the cell and parameter. The data is recorded on a 132 MB disc drive and if requested can be obtained in report form. The cell temperature during a test is controlled by a recirculating cooler that circulates a solution of water and ethylene glycol through a cooling plate.

**CELL DESCRIPTION – 48 Ah Flight Cells** – Six Air Force/Hughes recirculating design IPV nickel-hydrogen flight cells manufactured by Hughes are undergoing testing. Three of the cells contain 26 percent KOH electrolyte (test cells). The other three (control cells) are identical to the test cells except they contain 31 percent KOH. Both the test and control cells contain an equal number of components. The name plate capacity is 48 A hr. The cell is illustrated in Fig. 1. It consists of a stack of nickel electrodes, separators, hydrogen electrodes, and gas screen assembled in a non-back-to-back electrode configuration. In this configuration electrodes of different types directly face each other. The stack is packaged in a cylindrical pressure vessel, with hemispherical end caps. This is made of Inconel 718 and



lined with zirconium dioxide which serves as a wall wick. The components are shaped in a pineapple slice pattern. The electrodes are connected electrically in parallel. The separators consist of two layers of zircar, which extend beyond the electrodes to contact the wall wick. Hence, the electrolyte which leave the stack during cycling will be wicked back. The gas screens are polypropylene. The nickel electrode consists of a dry sinter plaque containing a nickel screen substrate which was electrochemically impregnated by the alcoholic Pickett process (Ref. 14).

**CELL DESCRIPTION – 125 Ah Advanced Flight Cells** – Six 125 Ah advanced design IPV nickel-hydrogen flight cells fabricated by Eagle-Picher, Joplin according to NASA Lewis specification are undergoing cycle life testing. The nickel electrodes were fabricated at Eagle Picher, Colorado Springs and were impregnated with active material by the alcoholic Pickett process (Ref. 14). Three of the cells (test cells) contain all of the advanced design features as described in Ref. 15. The other three cells (control cells) are the same as the test cells except they do not have catalyst on the wall wick. All six cells contain 26 rather than 31 percent KOH electrolyte.

The test cell design is illustrated in Fig. 2. The new features of this design which are not incorporated in the state-of-the-art Air Force/Hughes or COMSAT/Intelsat Cells are: (1) use of 26 rather than 31 percent KOH electrolyte which improves cycle life (Refs. 2, 3, and 16), (2) use of a catalyzed wall wick located on the inside surface of the pressure vessel wall which chemically recombines oxygen generated at the end of charge and on overcharge with hydrogen to form water. State-of-the-art nickel-hydrogen cells recombine the oxygen on the catalyzed hydrogen electrode surface in the stack. The catalyzed wall wick should improve oxygen and thermal management (Ref. 17), (3) use of serrated edge separators to facilitate gaseous oxygen and hydrogen flow within the cell, while still maintaining physical contact with the wall wick for electrolyte management, (4) use of a floating rather than a fixed stack (SOA) to accommodate nickel electrode expansion due to charge/discharge cycling. This is accomplished by use of Belleville disc springs located at each end of the stack. The significant improvements resulting from these innovations are extended cycle life, enhanced oxygen, thermal and electrolyte management, and accommodation of some of the nickel electrode expansions.

## RESULTS AND DISCUSSION

**48 Ah FLIGHT CELLS – Storage Test** – The nickel-hydrogen battery could undergo a planned or unplanned storage due to delays prior to launch. What effect will this have on performance? The influence of storage (31 days, trickle charged at C/200, 10 °C) on the capacity of the 48 Ah IPV nickel-hydrogen flight cells containing 26 and 31 percent KOH electrolyte is shown in Fig. 3. The spread in the data indicate there is no significant capacity loss after 31 days for either the 26 or 31 percent KOH cells.

**48 Ah FLIGHT CELLS – Performance Test** – A comparison of the average discharge voltage (three cells) as a function of time for the cells containing 26 and 31 percent KOH was made and is shown in Fig. 4. The voltage for the 26 percent KOH cells is higher than for the 31 percent KOH cells up to about an 82 percent DOD. The discharge rate was 1.4 C (67.2 A) and the cell temperature was maintained at 10 °C. The ampere-hour capacity for these cells is shown in Table I (1.4 C, 10 °C). The capacity on the average for the 26 percent KOH cells was about 10 percent lower than the 31 percent KOH cells. This relatively small decrease in initial capacity is traded for a significant increase in cycle life. It should be noted that the data in Table I is for a 100 percent DOD. In an actual application the DOD will be much less. For instance the DOD for Space Station Freedom will be about 35 percent. At this DOD the portion of the curve in Fig. 4 being operated at is where the cells containing 26 percent KOH have a higher discharge voltage, and still have adequate capacity reserve.

**48 Ah FLIGHT CELLS – Cycle Test** – The influence of LEO cycling at 80 percent DOD on the end of discharge voltage for the 48 Ah IPV nickel-hydrogen flight cells containing 26 percent KOH is summarized in Fig. 5. One of the cells failed at cycle 15 314. The other two cells have been cycled for over 18 000 cycles during the continuing test. The influence of cycling on the end of charge pressure for the 26 percent KOH cells is shown in Fig. 6. The pressure increase on the average is about 36 percent at cycle 10 634. The pressure increase could be indicative of nickel plaque corrosion which converts nickel to active material. The increase in pressure will result in a shift in the beginning of life state-of-charge versus pressure curve.

The influence of LEO cycling at 80 percent DOD on the end of discharge voltage for the cells containing 31 percent KOH is shown in Fig. 7. All three cells failed (cycle 3729, 4165, and 11 355). The failure mode for each cell was characterized by degradation of discharge voltage to 1.0 V. No cell failed due to an electrical short. A comparison of the discharge curve at the beginning and end of life for Cell 1, which failed at cycle 3729, is shown in Fig. 8. This information also shows a voltage degradation. The ampere-hour capacity decrease for cell 1 was about 33 percent (1.4 C rate, 10 °C), for cell 2, 33 percent, and for cell 3, 36 percent. The influence of cycling on the end of charge pressure for the 31 percent KOH cells is shown in Fig. 9. The pressure change can be correlated with the discharge voltage change due to cycling. The pressure increase for cell 3 at cycle 10 634 is 37 percent. The pressure increase is about the same as for the 26 percent KOH cells which on the average was 36 percent at this cycle.

The superior performance of the 26 percent KOH cells compared to the 31 percent cells is in agreement with boiler plate cell results reported previously (2 and 3). It is attributed to a crystallographic change of active material (Ref. 16). Gamma NiOOH is converted to beta



NiOOH in 26 percent KOH. Beta NiOOH has a lower capacity but longer life.

**48 Ah FLIGHT CELLS – Destructive Physical Analysis** – Destructive physical analysis (DPA) of all three of the 31 percent KOH cells was completed and documented at Hughes under a NASA Lewis Contract (Ref. 18). DPA of the 26 percent cell is in process. A summary of the DPA results of the 31 percent KOH cells is as follows: All three cells failed during cycling due to a decrease in voltage and nickel-electrode capacity. The capacity decrease was confirmed by measuring nickel-electrode capacity in flooded electrolyte cells. Some observations which could cause the capacity decrease are nickel-electrode expansion, rupture and corrosion of the nickel-electrode substrate, active material redistribution, and accumulation of electrochemically undischARGEable active material with cycling. Cell 3 appears to have failed by gradual wear-out due to these changes. Some of the electrodes from cells 1 and 2 showed a premature capacity fading which was responsible for early failure. However, chemical analysis of these electrodes did not show anomalous results. The mechanism of the premature capacity fading is not fully understood by the present DPA. No cells failed due to an electrical short. All cells showed some increase in internal resistance after the cycle test; however, this increase itself does not appear to be the direct cause of failure. All cells showed a decrease in discharge voltage and an increase in charge voltage after the cycle test.

**125 Ah ADVANCED FLIGHT CELLS, Cell Performance** – For a representative 125 Ah advanced catalyzed wall wick nickel-hydrogen flight battery cell the voltage and pressure during charge and discharge are shown in Fig. 10 (beginning of life). The discharge rate was 0.69 C (87 A) and the temperature was a nominal 10 °C. The mid-discharge voltage was 1.248 V. The pressure, as expected, varies linearly with the state-of-charge. It should be noted, however, that the pressure could increase with charge/discharge cycling causing a shift in the state-of-charge curve.

The effect of discharge rate on ampere-hour capacity for a representative cell of each type is shown in Fig. 11. The capacity decreased slightly (1 percent) over the range of C/2 to 1.4 C, after which point it decreased rapidly. In a nickel-hydrogen cell the gaseous hydrogen comes into contact with the nickel electrodes resulting in a capacity loss due to self discharge. The capacity retention of the cells after a 72 hr open circuit stand at 10 °C is shown in Fig. 12. The data shows no significant difference in capacity retention between the catalyzed and noncatalyzed wall wick cells. The capacity retention for the catalyzed wall wick cells on the average is 84 percent and for the noncatalyzed wall wick cells is 85 percent.

**125 Ah ADVANCED FLIGHT CELLS – Storage Test** – The effect of storage (52 days, discharged, open circuit, 0 °C) on the capacity of the six 125 Ah flight IPV nickel-hydrogen cells is summarized in Fig. 13. The spread in the data shows no significant capacity loss for

either the catalyzed or noncatalyzed wall wick cells due to the 52 day storage. Actually, there was a slight average increase in capacity for both the catalyzed and noncatalyzed wall wick cells.

**125 Ah ADVANCED FLIGHT CELLS – Cycle Test** – The influence of LEO cycling at 60 percent DOD on the end of discharge voltage for the 125 Ah catalyzed wall wick IPV nickel-hydrogen flight cells is summarized in Fig. 14. After 16 000 cycles there has been no cell failure in the continuing test. The influence of cycling on the end of charge pressure for the catalyzed wall wick cells is shown in Fig. 15. No pressure for cell 2 is available because the cell had a bad strain gauge. For cells 1 and 3 the pressure increased relatively rapidly up to about cycle 1400 then decreased. The average pressure increase at cycle 1400 is about 11 percent higher than at the beginning of life.

The influence of LEO cycling at 60 percent DOD on the end of discharge voltage for the 125 Ah noncatalyzed wall wick IPV nickel-hydrogen flight cells is shown in Fig. 16. Two of the three cells failed (cycles 9588 and 13 900). The failure was characterized by degradation of end of discharge voltage to 1.0 V. The cells did not fail due to an electrical short. The influence of cycling on the end of charge pressure for the noncatalyzed wall wick cells is shown on Fig. 17. The pressure for the three cells increased up to about cycle 2000 then decreased. The average pressure increase at cycle 2000 is about 9 percent higher than at the beginning of life.

The cycle life testing will continue until cell failure. A post-cycle teardown and failure analysis will be conducted to evaluate the cause of failure. This information will be used to effect further improvements.

## CONCLUDING REMARKS

A breakthrough in the LEO cycle life of individual pressure vessel nickel-hydrogen battery cells was reported. The cycle life of boiler plate cells containing 26 percent KOH electrolyte was about 40 000 accelerated LEO cycles at 80 percent DOD compared to 3500 cycles for cells containing 31 percent KOH. Results of the boiler plate cell test are in the process of being validated at NWSC, Crane, Indiana. Forty-eight ampere-hour flight cells containing 26 and 31 percent KOH are undergoing real time LEO cycle life testing at an 80 percent DOD, 10 °C. All three cells containing 31 percent KOH failed (cycle 3729, 4165, and 11 355). One of the 26 percent KOH cells failed at cycle 15 314. The other two 26 percent KOH cells have been cycled for over 18 000 cycles during the continuing test.

Validation testing of NASA Lewis 125 Ah advanced design IPV nickel-hydrogen flight cells is also being conducted at NWSC, Crane, Indiana under a NASA Lewis Contract. This consists of characterization, storage, and cycle life testing. There was no capacity degradation after 52 days of storage with the cells in the discharged state, on open circuit, 0 °C, and a hydrogen pressure of 14.5 psia. The catalyzed wall wick cells have been



cycled for over 16 000 cycles with no cell failures in the continuing test. Two of the noncatalyzed wall wick cells failed (cycles 9588 and 13 900).

## REFERENCES

1. L. Miller, "The Ni-H<sub>2</sub> Battery System: A Space Flight Application Summary," 1988 IECEC; Proceedings of the Twenty-Third Intersociety Energy Conversion Engineering Conference, Vol. 2, ASME, New York, 1988, pp. 489-492.
2. H. S. Lim, and S. A. Verzwylt, "KOH Concentration Effect on Cycle Life of Nickel-Hydrogen Cells, III. Cycle Life Test," Journal of Power Sources, Vol. 22, Mar.-Apr. 1988, pp. 213-220.
3. H. S. Lim, and S. A. Verzwylt, "KOH Concentration Effect on the Cycle Life of Nickel-Hydrogen Cells. IV. Results of Failure Analysis," Journal of Power Sources. Vol. 29, Feb. 1990, pp. 503-519.
4. E. Adler, T. Duranti, P. Frisch, T. Jacewicz, H. Rogers, L. Samoss, S. Stadnick, and L. Tinker, "Nickel-Hydrogen Battery Advanced Development Program," AFWAL-TR-80-2044, Hughes Aircraft Company, 1980.
5. D. Warnock, "Life Test of 50 AH NiH<sub>2</sub> Battery," The 1981 Goddard Space Flight Center Workshop, G. Halpert, ed., NASA CP-2217, 1982, pp. 487-500.
6. J. J. Smithrick, "Cycle Life Test and Failure Model of Nickel-Hydrogen Cells," IECEC '83: Proceedings of the Eighteenth Intersociety Energy Conversion Engineering Conference, Vol. 4, AIChE, New York, 1983, pp. 1535-1542.
7. D. H. Fritts, "Testing the Mechanical Characteristics of Sintered Nickel-Battery Plaque and Their Relationship to Nickel-Electrode Performance," Journal of Power Sources, Vol. 6, Apr. 1981, pp. 171-184.
8. D. F. Pickett, H. H. Rogers, L. A. Tinker, C. A. Bleser, J. M. Hill, and J. S. Meador, "Establishment of Parameters for Production of Long Life Nickel Oxide Electrodes for Nickel-Hydrogen Cells," Energy to the 21st Century; Proceedings of the Fifteenth Intersociety Energy Conversion Engineering Conference, Vol. 3, AIAA, New York, 1980, pp. 1918-1924.
9. V. C. Mueller, "Failure Analysis of Nickel Hydrogen Cell Subjected to Simulated Low Earth Orbit Cycling," The 1983 Goddard Space Flight Center Battery Workshop, D. Baer and G. W. Morrow, eds., NASA CP-2331, 1983, pp. 523-538.
10. K. M. Abbey, and D. L. Britton, "Electrolyte Management in Porous Battery Components - Static Measurements," NASA TM-83073, 1982.
11. J.J. Smithrick, "Initial Performance of Advanced Designs for IPV Nickel-Hydrogen Cells," Power Sources 11: Research and Development in Non-Mechanical Electrical Power Sources, L. J. Pearce, ed., International Power Sources Symposium Committee, Leatherhead, England, 1986, pp. 215-226. (Also, NASA TM-87282.)
12. J.J. Smithrick, and S.W. Hall, "Effect of KOH Concentration on LEO Cycle Life of IPV Nickel-Hydrogen Flight Cells - An Update," Proceedings of the 26th Intersociety Energy Conversion Engineering Conference, IECEC '91, D.C. Black, ed., Vol. 3, American Nuclear Society, 1991, pp. 276-281.
13. J.J. Smithrick, and S.W. Hall, "Effect of LEO Cycling on 125 Ah Advanced Design IPV Nickel-Hydrogen Flight Cells - An Update," Proceedings of the 25th Intersociety Energy Conversion Engineering Conference, IECEC '91, D.L. Black, ed, Vol. 3, American Nuclear Society, 1991, pp. 311-317.
14. D.F. Pickett, "Preparation of Nickel Electrodes," U.S. Patent 3,827,911, Aug. 1974.
15. J.J. Smithrick, M.A. Manzo, and O. Gonzalez-Sanabria, "Advanced Designs for IPV Nickel-Hydrogen Cells," IECEC '84: Advanced Energy Systems - Their role in Our Future; Proceedings of the Nineteenth Intersociety Energy Conversion Engineering Conference, Vol. 1 American Nuclear Society, New York, 1984, pp. 631-635. (Also, NASA TM-83643.)
16. H.S. Lim, and S.A. Verzwylt, "Electrochemical Behavior of Heavily Cycled Nickel Electrodes in Ni H<sub>2</sub> Cells Containing Electrolytes of Various KOH Concentration," Proceedings of the Symposium on Nickel Hydroxide Electrodes, D.A. Corrigan, A.A. Zimmerman, eds., Electrochemical Society Proc., Vol. 90-4, Electrochemical Society, 1990, pp. 341-355.
17. O.D. Gonzalez-Sanabria, "Effect of NASA Advanced Designs on Thermal Behavior of Ni-H<sub>2</sub> Cells," 1988 IECEC; Proceedings of the Twenty-Third Intersociety Energy Conversion Engineering Conference, D.Y. Goswami, ed., Vol. 2, ASME, New York, 1988, pp. 453-456.
18. H.S. Lim, G.R. Zelter, T.T. Smithrick, and S.W. Hall, "Destructive Physical Analysis Results of Ni/H<sub>2</sub> Cells Cycled in LEO Regime," Proceedings of the 26th Intersociety Energy Conversion Engineering Conference, ECEC '91, D.L. Black, ed., Vol. 3, American Nuclear Society, 1991, pp. 304-310.



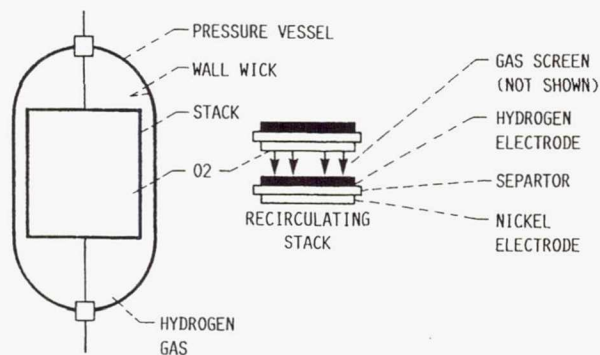


FIGURE 1.—ILLUSTRATION OF HUGHES RECIRCULATING STACK INDIVIDUAL PRESSURE VESSEL NICKEL-HYDROGEN CELL.

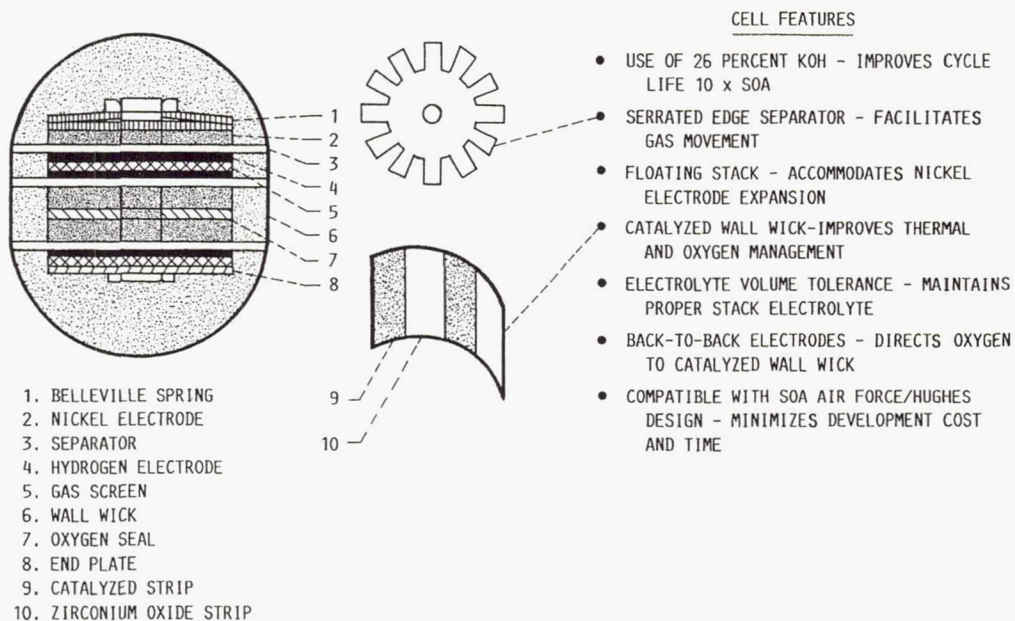


FIGURE 2.—NASA ADVANCED DESIGN IPV NICKEL-HYDROGEN CELL-CATALYZED WALL WICK.



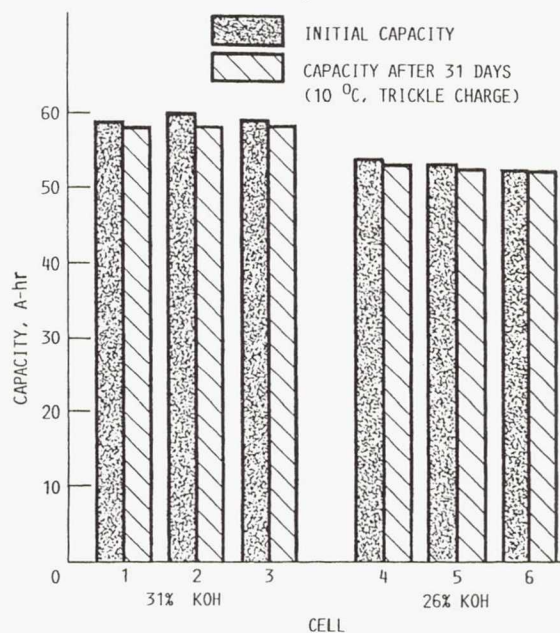


FIGURE 3.—EFFECT OF STORAGE ON CAPACITY OF 48 A-hr HUGHES IPV Ni/H<sub>2</sub> FLIGHT CELLS.

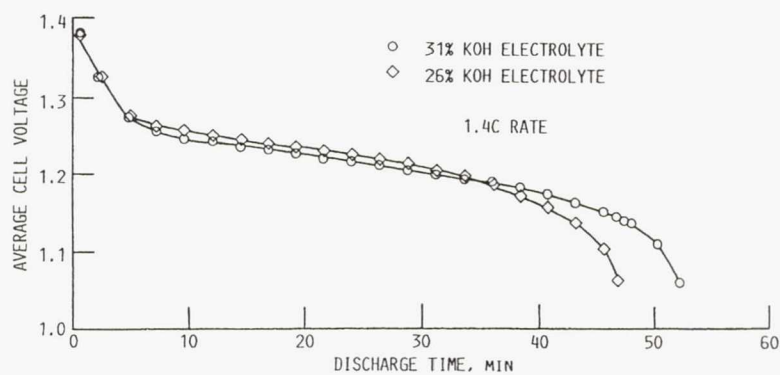


FIGURE 4.—COMPARISON OF HUGHES 48 A-hr IPV Ni/H<sub>2</sub> FLIGHT CELLS CONTAINING 26 PERCENT AND 31 PERCENT KOH ELECTROLYTE.



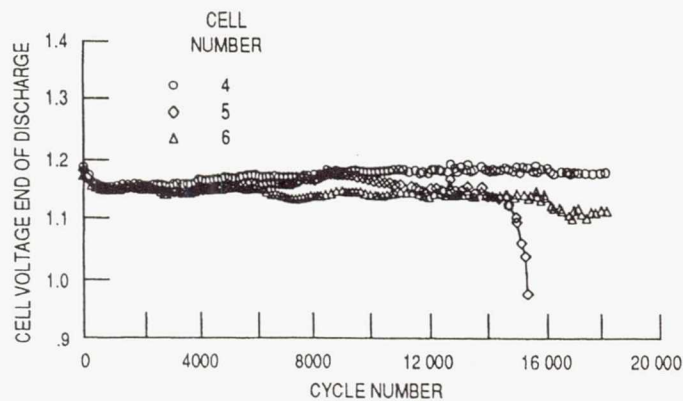


FIGURE 5.—EFFECT OF LEO CYCLING AT 80 PERCENT DOD ON 48 A-hr IPV HUGHES FLIGHT CELLS CONTAINING 26 PERCENT KOH ELECTROLYTE, 10 °C. TEST CONDUCTED AT NWSC, CRANE.

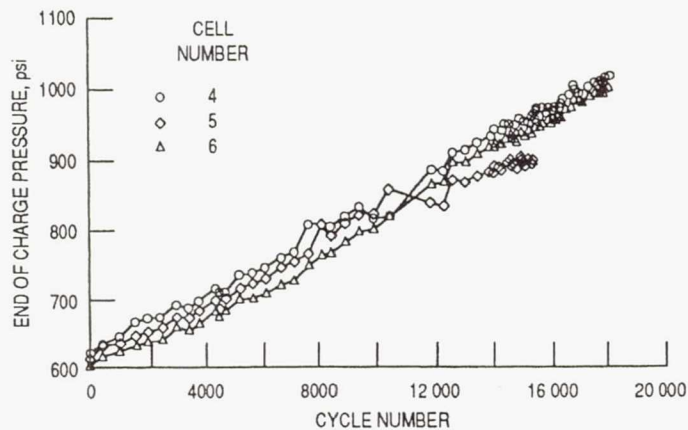


FIGURE 6.—EFFECT OF LEO CYCLING AT 80 PERCENT DOD ON 48 A-hr IPV HUGHES FLIGHT CELLS CONTAINING 26 PERCENT KOH.

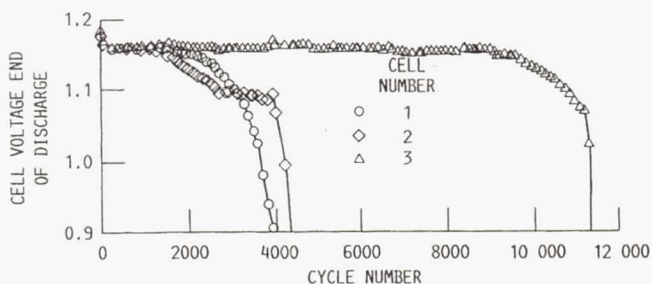


FIGURE 7.—EFFECT OF LEO CYCLING AT 80 PERCENT DOD ON HUGHES FLIGHT CELLS CONTAINING 31 PERCENT KOH ELECTROLYTE, 10 °C.

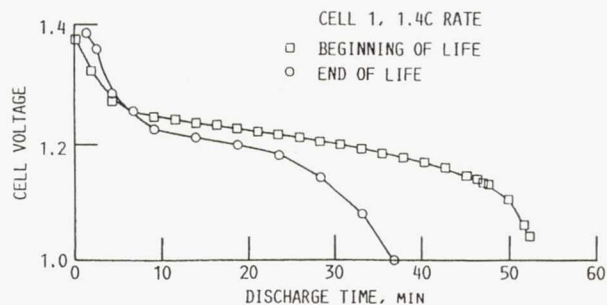


FIGURE 8.—CELL VOLTAGE FOR HUGHES 48 A-hr IPV Ni/H<sub>2</sub> FLIGHT CELL CONTAINING 31 PERCENT KOH ELECTROLYTE.



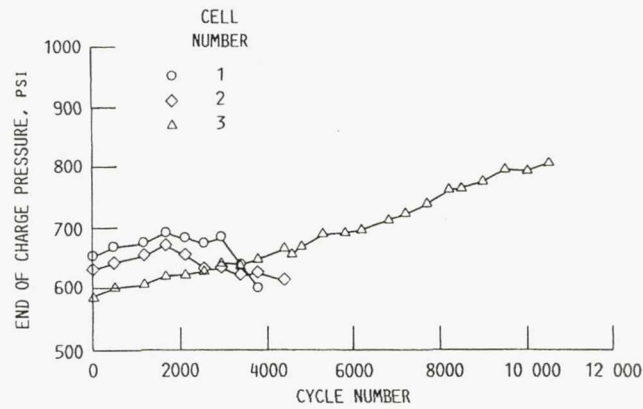


FIGURE 9.—EFFECT OF LEO CYCLING AT 80 PERCENT DOD ON HUGHES FLIGHT CELLS CONTAINING 31 PERCENT KOH.

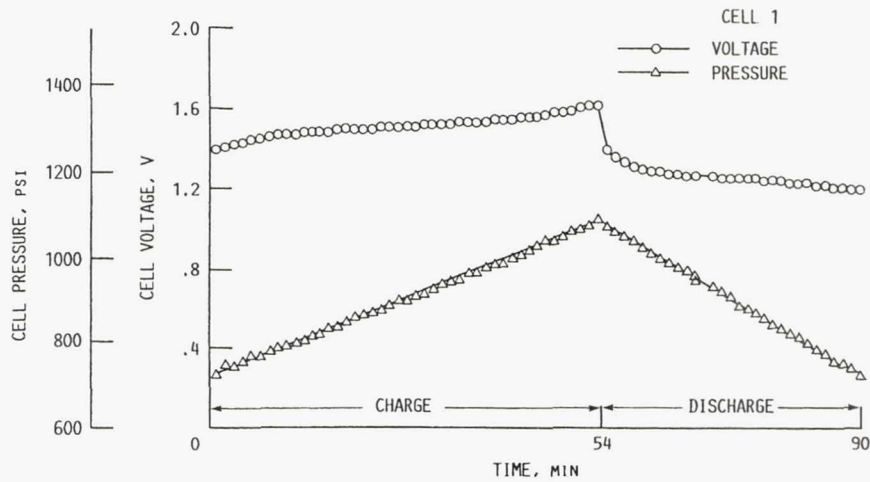


FIGURE 10.—CELL VOLTAGE AND PRESSURE DURING CHARGE AND DISCHARGE FOR A REPRESENTATIVE 125 A-hr ADVANCED CATALYZED WALL WICK IPV  $\text{Ni}/\text{H}_2$  FLIGHT BATTERY.

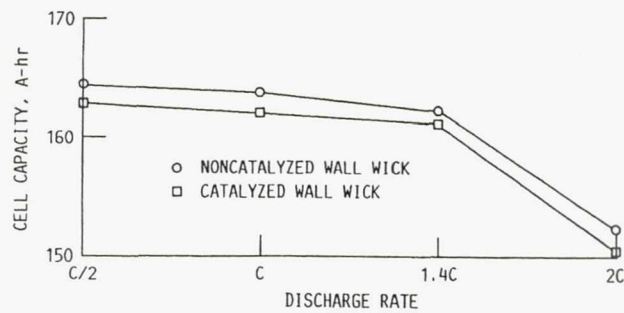


FIGURE 11.—COMPARISON OF EAGLE-PICHER 125 A-hr  $\text{Ni}/\text{H}_2$  CELLS CATALYZED AND NONCATALYZED WALL WICK.

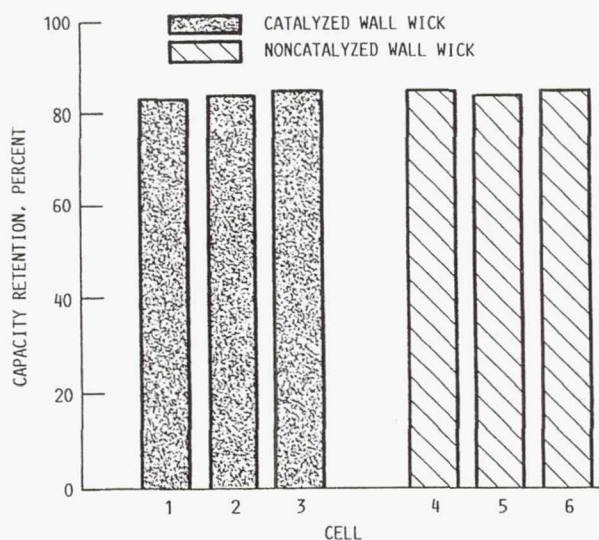


FIGURE 12.—CAPACITY RETENTION OF 125 A-hr EAGLE-PICHER ADVANCED IPV  $\text{Ni}/\text{H}_2$  FLIGHT CELLS AFTER 72 hr OPEN CIRCUIT STAND.

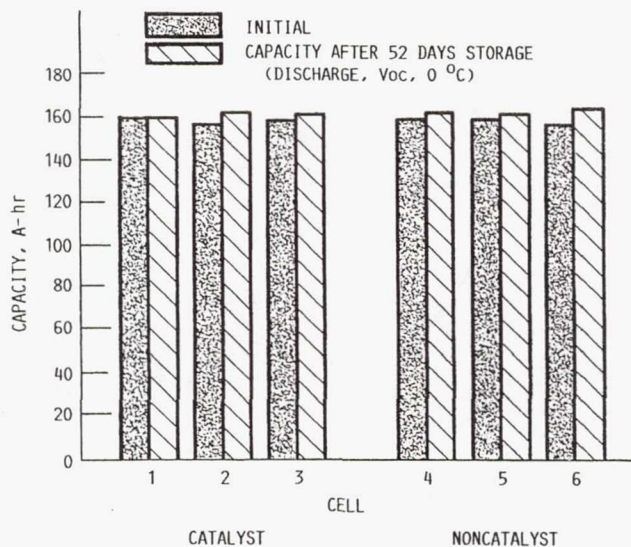


FIGURE 13.—EFFECT OF STORAGE ON CAPACITY OF 125 A-hr EAGLE-PICHER ADVANCED FLIGHT IPV  $\text{Ni}/\text{H}_2$  CELLS, CATALYZED AND NONCATALYZED WALL WICK, 26 PERCENT KOH.

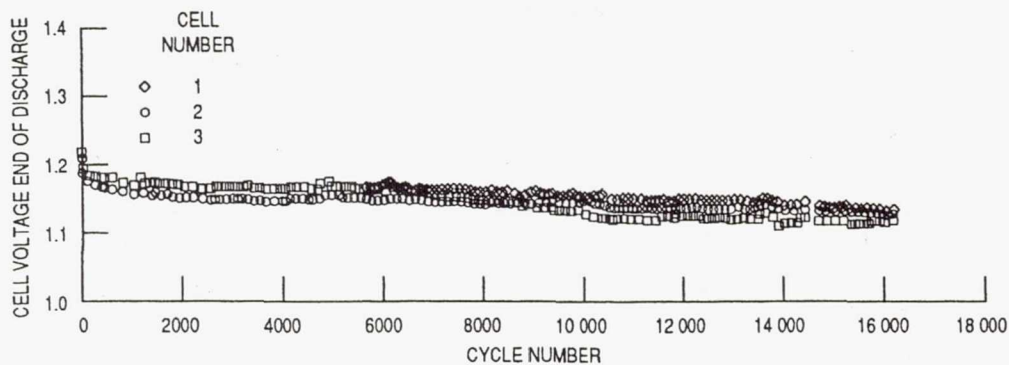


FIGURE 14.—EFFECT OF LEO CYCLING ON 125 A-hr NASA LEWIS ADVANCED CATALYZED WALL WICK IPV  $\text{Ni}/\text{H}_2$  CELLS MANUFACTURED BY EAGLE-PICHER - 26 PERCENT KOH, 60 PERCENT DOD, 10° C. TEST CONDUCTED AT NWSC, CRANE.

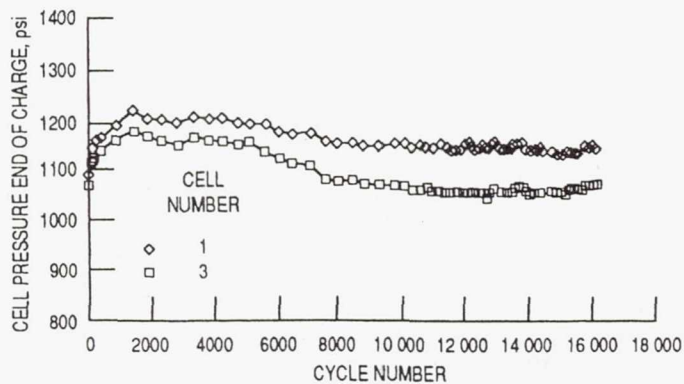


FIGURE 15.—EFFECT OF LEO CYCLING ON 125 A-hr NASA LEWIS ADVANCED CATALYZED WALL WICK IPV  $\text{Ni}/\text{H}_2$  CELLS MANUFACTURED BY EAGLE-PICHER.



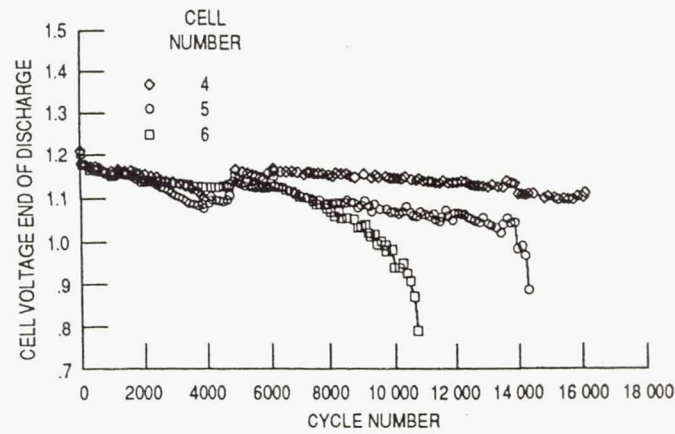


FIGURE 16.—EFFECT OF LEO CYCLING ON 125 A-hr NASA LEWIS ADVANCED NON-CATALYZED WALL WICK IPV  $\text{Ni}/\text{H}_2$  CELLS MANUFACTURED BY EAGLE-PICHER - 26 PERCENT KOH, 60 PERCENT DOD, 10 °C. TEST CONDUCTED AT NWSC, CRANE

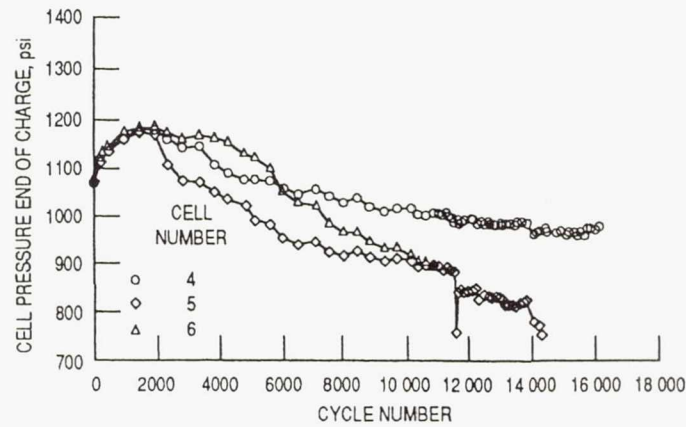


FIGURE 17.—EFFECT OF LEO CYCLING ON 125 A-hr NASA LEWIS ADVANCED NONCATALYZED WALL WICK IPV  $\text{Ni}/\text{H}_2$  CELLS MANUFACTURED BY EAGLE-PICHER.

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 1992	3. REPORT TYPE AND DATES COVERED Technical Memorandum	
4. TITLE AND SUBTITLE Validation Test of Advanced Technology for IPV Nickel-Hydrogen Flight Cells—Update			5. FUNDING NUMBERS  WU-506-41-21	
6. AUTHOR(S) John J. Smithrick and Stephen W. Hall				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191			8. PERFORMING ORGANIZATION REPORT NUMBER  E-7069	
9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Washington, D.C. 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NASA TM-105689	
11. SUPPLEMENTARY NOTES Prepared for the 27th Intersociety Energy Conversion Engineering Conference cosponsored by the SAE, ACS, AIAA, ASME, IEEE, AIChE, and ANS. John J. Smithrick, NASA Lewis Research Center. Stephen W. Hall, Naval Weapon Support Center, Crane, Indiana 47522. Responsible person, John J. Smithrick, (216) 433-5255.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified - Unlimited Subject Category 20			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  Individual pressure vessel (IPV) nickel-hydrogen technology was advanced at NASA Lewis and under Lewis contracts with the intention of improving cycle life and performance. One advancement was to use 26 percent potassium hydroxide (KOH) electrolyte to improve cycle life. Another advancement was to modify the state-of-the-art cell design to eliminate identified failure modes. The modified design is referred to as the advanced design. A breakthrough in the low-earth-orbit (LEO) cycle life of IPV nickel-hydrogen cells has been previously reported. The cycle life of boiler plate cells containing 26 percent KOH electrolyte was about 40 000 LEO cycles compared to 3500 cycles for cells containing 31 percent KOH. The boiler plate test results are in the process of being validated using flight hardware and real time LEO test at the Naval Weapons Support Center (NWSC), Crane, Indiana under a NASA Lewis Contract. An advanced 125 Ah IPV nickel-hydrogen cell was designed. The primary function of the advanced cell, is to store and deliver energy for long-term, LEO spacecraft missions. The new features of this design are: (1) use of 26 percent rather than 31 percent KOH electrolyte, (2) use of a patented catalyzed wall wick, (3) use of serrated-edge separators to facilitate gaseous oxygen and hydrogen flow within the cell, while still maintaining physical contact with the wall wick for electrolyte management, and (4) use of a floating rather than a fixed stack (state-of-the-art) to accommodate nickel electrode expansion due to charge/discharge cycling. The significant improvements resulting from these innovations are extended cycle life; enhanced thermal, electrolyte, and oxygen management; and accommodation of nickel electrode expansion. The advanced cell design is in the process of being validated using real time LEO cycle life testing of NWSC, Crane, Indiana. An update of validation test results confirming this technology is presented.				
14. SUBJECT TERMS Nickel hydrogen batteries; Alkaline batteries; Storage batteries			15. NUMBER OF PAGES 12	
			16. PRICE CODE A03	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	